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ROOTSTOCKS SIMILAR TO SOUR ORANGE FOR FLORIDA CITRUS TREES

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Abstract. **Citrus tristeza virus (CTV) has, in recent years, caused significant loss of trees on sour orange (*C. aurantium* L.) in Florida. Possible alternative rootstocks with characteristics similar to sour orange but that are less susceptible or tolerant to CTV are Smooth Flat Seville (SFS), Gou Tou, Zhu Luan, and *C. obovoidea* Hort. ex Tak. Isozyme genotypes were developed based on 5 enzyme systems. Zhu Luan, *C. obovoidea* and SFS were identical except at one locus, and all were different from sour orange at 3 loci. The characteristics of each rootstock are described based on several sources but primarily data from Florida field trials and commercial plantings. Orange and grapefruit trees on SFS in 11 commercial sites were horticulturally similar to trees on sour orange, grew well in high pH soil, and the incidences of blight and phytophthora foot rot were low. Individual tree size was variable at each grove site because of trees on zygotic seedlings as demonstrated by isozyme analysis. Many trees on SFS indexed positive for severe CTV strains but appeared unaffected. A small number of declining and/or stunted trees on SFS were observed but not all were infected with severe CTV. Preliminary indications were that Gou Tou and *C. obovoidea* are tolerant to Florida severe CTV strains; Zhu Luan is untested. Trees on Bittersweet sour orange at 7 sites were also included in the field survey. Virtually all the sampled trees indexed positive for mild CTV strains but were unaffected; trees with severe strains had declined. Bittersweet and standard sour orange were isozymically identical.**

In commercial citriculture, sour orange has been a universal rootstock that is well-known for many attributes related especially to yield, fruit and juice quality, and tolerance to cold temperatures and various soil conditions (Castle, 1987). For these reasons, sour orange has been a popular rootstock in Florida as well, particularly among fresh fruit growers.

Sour orange has one major weakness—it is highly susceptible to decline isolates of citrus tristeza virus (CTV). This aphid-vectored virus is spreading throughout the world and is the main reason the use of sour orange has declined in many countries and in Florida; however, CTV has only sporadically threatened sour orange use in Florida until recently. It is now clear that severe decline and stunting CTV strains are present locally and are being spread via infected budwood sources (Garnsey, 1990; Garnsey et al., 1980).

Florida citrus growers are reluctant to give up sour orange because it is considered unmatched as a rootstock for producing fresh-market grapefruit and other cultivars, and superior in its adaptation to chronically wet and calcareous grove sites. Therefore, the purpose of this report was to review existing information and to present new data about rootstocks that might be acceptable substitutes for sour orange based primarily on their known or purported tolerance to CTV.

Materials and Methods

The characteristics of Smooth Flat Seville (SFS; also known as Australian sour orange), *C. obovoidea* (common name: Kinkôji), Gou Tou, Zhu Luan, and Bittersweet sour orange (BSO) are described herein. Bittersweet is a sour orange cultivar; the other rootstocks are putative hybrids most likely involving pummelo [*C. grandis* (L.) Osbeck], mandarin (*C. reticulata* Blanco), and sour orange (Barrett and Rhodes, 1976; Hodgson, 1967).

Information about these rootstocks was obtained from published literature, commercial Florida groves, the Division of Plant Industry (DPI) Citrus Budwood Registration Bureau Foundation Grove in Dundee, and 2 field experiments. Grove evaluations and data were obtained during a visit to each site between Aug. and Nov. 1992. Most trees at each site were observed to form an overall impression of their condition, uniformity, size, and current crop. The extent of tree decline and probable causes, and the number of apparent replants were noted. Also at each site, if there were trees of comparable age on sour orange, they were included in the survey. A small number of soil samples, 0 to 6 inches deep, were collected for pH measurement. Samples of 5 to 10 fully expanded recent flush leaves per tree were taken from a total of 5 to 10 healthy, stunted, or declining trees located throughout each block. The number of samples increased with the size of the planting. Leaf sap was expressed from each sample and examined by double antibody sandwich enzyme linked immunosorbent assay (DAS-ELISA) with polyclonal antibodies to detect the presence of CTV and by indirect monoclonal antibody MCA 13 to detect the presence of CTV strains capable of inducing decline on sour orange rootstock (Permar et al., 1990) and for blight-related proteins (Derrick et al., 1990). In addition, rootstock bark samples or rootsprout leaves were collected from some of the same trees for isozyme analysis to confirm rootstock identity and to distinguish zygotic from nucellar rootstocks as a possible explanation of tree condition. Isozyme genotypes were determined by starch gel electrophoretic analysis of expressed sap for phosphoglucose isomerase (PGI), phosphoglucomutase (PGM), peroxidase (PER), glutamate oxaloace-

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tate transaminase (GOT), malate dehydrogenase (MDH), shikimate dehydrogenase (SkDH), and phosphoglucodehydrogenase (PGD). The genotypes of the field samples were compared to nucellar genotypes developed from plant material in the DPI Arboretum, Winter Haven. The sour orange and Bittersweet sour orange in this collection were local selections, the SFS is the Appleby selection from Australia (Grimm and Garnsey, 1968), the Gou Tou (Garnsey, 1992) and Zhu Luan were obtained from China, and the *C. obovoidea* from a University of California germplasm collection.

The 2 field trials are located at Fort Pierce and St. Cloud. The former is a corporate experiment of nucellar 'Valencia' sweet orange on 6 rootstocks planted in Sept. 1973 on a 4-row bed with unreplicated groups of 40 trees; spacing 15 × 25 ft. The second trial consists of 'Hamlin' (1-4-1) trees on sour orange, BSO, SFS, *C. obovoidea*, and other rootstocks planted 14 × 22 ft in Sept. 1986. There are 6 replications of 3-tree plots. Leaf samples were collected from each tree on the 4 rootstocks for CTV indexing.

Results

The commercial plantings of trees on SFS (Table 1) were in excellent overall condition with virtually no evidence of phytophthora foot rot or nutritional problems regardless of the soil pH. Tree sizes and current crops were typical or above average for the tree ages and when compared to nearby trees on sour orange of similar age; however, within the sites of older trees, there was a consistent lack of uniformity in tree height. The normal variation expected from soil effects was present but, in addition, adjacent trees within rows were noticeably uneven. Each planting had a few apparently healthy but stunted trees and some declining trees that together appeared to be < 1% of the total number of trees. Other results were as follows:

Grove A. Soil pH 7-8; 4 healthy trees were sampled and indexed positive for mild CTV strains (DAS-ELISA), negative for severe strains (MCA 13), and negative for blight proteins; of 3 declining trees sampled, 2 indexed positive for both mild and severe CTV strains and blight. Two zygotic rootstocks and 2 standard sour oranges were identified among bark samples examined from 6 trees.

Grove B. This grove is adjacent to the epicenter of St. Lucie County's most severe CTV outbreak. Fifty leaf samples were systematically collected from this site and indexed for CTV only; 40 were positive for severe CTV and all were positive for mild strains. Isozyme genotypes for rootstock bark samples from 10 trees were nucellar SFS.

Grove C. Soil pH 7-8; complete tree status surveys of this planting and an adjacent one on sour orange were conducted and there were virtually no trees in either group with foot rot or blight. Eight percent of the trees on sour orange showed decline symptoms typical of Florida severe CTV strains, but none of the trees on SFS showed decline. Leaf samples from 3 healthy trees on SFS indicated the presence of mild CTV strains. Rootstock bark samples had the nucellar isozyme genotype for SFS.

Grove D. This site was originally planted with trees on rough lemon. When tree loss from blight reached 80%, the remaining trees were removed and the block replanted in 1976 with trees on SFS. Half of the planting was visually mapped in 1992 and ca. 75% of the trees were symptomless, 5% appeared to be blighted, 10% were stunted but seemed healthy and 3% were stunted and declining. Leaf samples were collected from 17 symptomless trees which all indexed positive for mild CTV and 12 indexed positive for severe CTV strains; 3 healthy, stunted trees were mild CTV positive only and were on zygotic SFS; 2 declining, normal-sized trees indexed either blight protein or severe CTV positive. Tree loss from CTV was occurring in nearby trees on sour orange.

Grove E. Only mild CTV strains were detected and no declining or blighted trees were observed. Four of 6 rootstock bark samples from normal-sized and stunted healthy trees were zygotic SFS.

Grove F. Soil pH 7.7-8.0; trees in one area were micronutrient deficient; 7 of 9 leaf samples indexed positive for mild but not severe CTV strains or blight proteins. One of 7 bark samples was zygotic and the others were nucellar SFS.

Grove G. Leaves of symptomless and declining trees (6 each) were sampled; only 3 of the 12 were mild CTV strain positive and one symptomless tree was severe strain posi-

Table 1. General descriptions of the commercial grove sites.

Grove	Location	Scion	Rootstock[z]	Tree age, yr	Planting size
A	Southern Indian River County	Navel	SFS	11	20 acres
B	Ft. Pierce	Navel	SFS	10	40 acres
C	Ft. Pierce	Navel	SFS	12	5 acres
D	Ft. Pierce	Hamlin	SFS	16	10 acres
E	Ft. Pierce	Redblush	SFS	16	10 acres
F	North Okeechobee	Hamlin	SFS	10	17 acres
G	Clewiston	Hamlin	SFS	15	116 acres
H	St. Cloud	Valencia	SFS	17	20 trees
I	Zolfo Springs	Hamlin	SFS	3	15 acres
J	Zolfo Springs	Murcott	BSO	20+	5+ acres
K	Ona	Valencia	BSO	25+	40 acres
L	Ona	Parson Brown	BSO	10+	40 acres
M	Nocatee	Valencia	BSO	10	40 acres
N	Ona	Hamlin	BSO	5	40 acres

[z]SFS = Smooth Flat Seville; BSO = Bittersweet sour orange.

tive; the 6 declining trees were blight protein positive and all the symptomless ones were negative; virtually the same result was obtained with 12 samples from nearby 'Valencia' trees on SFS.

Grove H. The trees in this planting on SFS or sour orange were large with an acceptable crop and appeared healthy even though CTV assays of 8 leaf samples collected from the 2 sets of trees showed the presence of severe strains. Among nearby trees on rough lemon, Cleopatra mandarin and Carrizo citrange, < 50% remained due to losses from freeze damage and blight while 90% of those on SFS or sour orange had survived.

Grove I. This young planting was apparently undamaged by the 1989 freeze although it is unknown if the trees were protected in any way; only mild CTV strains were found in the 2 leaf samples taken and no blight proteins were detected. One of 3 rootstock samples was identified as a SFS zygotic.

Groves J-N. The trees at these sites were on Bittersweet sour orange (BSO). Virtually all trees were in excellent condition, but those sampled were infected with mild CTV strains. Several declining trees were sampled and indexed positive for severe CTV strains.

Field trials. Soil pH at the Ft. Pierce site was 6.7. The 'Valencia' trees on SFS were healthy, infected with mild CTV isolates only and leaf sap from 2 apparently blighted trees did not react to the tests for blight proteins. Healthy-looking but stunted trees were observed. Isozyme results for those and normal-sized trees indicated the nucellar SFS genotype. The current crop seemed comparable to nearby trees on Carrizo citrange and to exceed that of trees on Cleopatra mandarin.

Trees on SFS in the St. Cloud trial were similar in height to (data not shown) and yielded as well as those on Carrizo and Swingle but juice quality was lower in the one year reported (Table 2). The trees on SFS survived the 1989 freeze well and were in generally better condition than those on Carrizo or Swingle. All the trees on SFS or *C. obovoidea* were infected with a severe CTV strain as were most of the trees on sour orange or BSO. Trees on the latter 2 rootstocks were stunted but a few trees were infected with only mild strains and they were normal-sized.

DPI Foundation grove. Twenty-one trees of young nucellar 'Valencia' budlines on Gou Tou were planted at the DPI grove near Dundee in 1990. These trees were indexed for CTV 2 yr later and all were positive for severe strains except 2 trees which apparently were only infected with mild CTV strains. Among the trees with severe strains, 4 were stunted and 11 seemed less vigorous than those with the mild CTV strains which may be partly attributed to differences in tree size at the time of planting. In May 1985, 25 'Valencia' trees on BSO were planted and all were CTV-free at that time except for 8 that were infected with severe strains. In March 1992, the 8 trees with severe CTV strains were stunted or performing poorly.

In 1973, 1974 and 1975, a total of nearly 200 trees of registered sweet orange and grapefruit budlines on SFS were planted at the Foundation Grove, Dundee. Virtually all of those trees were or became infected with severe CTV strains by natural spread. To date, only 5 trees are stunted or considered unsatisfactory due to CTV effects. However, many trees of the same grapefruit scions on sour orange (52 trees originally) have declined from CTV (Youtsey and Hebb, 1982). Furthermore, the trees on SFS or Cleopatra survived the freezes of the 1980s in the best condition among 25 rootstocks represented in the Foundation Grove; also, there has been no loss to blight after ca. 17 yr for the trees on SFS while there has been decline in adjacent trees on Carrizo, rough lemon, et al. (Youtsey and Rosenthal, 1986). Yield data from the unreplicated Foundation Grove plantings indicate that trees on SFS may not be as productive as those on Carrizo but are comparable to trees on Swingle (Table 3).

Isozyme genotype. The isozyme genotypes of sour orange and Bittersweet sour orange were identical and differed from those of SFS, Zhu Luan and *C. obovoidea* at 3 of the 5 enzyme systems examined (Table 4). Among the 4 putative hybrids, SFS, Zhu Luan and *C. obovoidea* had identical genotypes except at the SkDH locus. Gou Tou is different from sour orange and the other rootstocks.

Discussion

Smooth Flat Seville. The taxonomic status of SFS is unknown. Hodgson (1967) suggested that it may be a natural hybrid between sour orange and 'Poorman' orange that occurred in Australia; however, our isozyme data and the results of Barrett and Rhodes (1976) seem to indicate that other parents were involved. 'Poorman' is probably a pummelo-mandarin hybrid and certain pummelo characteristics, particularly its monoembryony which leads to the production of zygotic embryos, are evident in SFS. Smooth Flat Seville seeds are polyembryonic but produce many zygotic seedlings. The relationship of this variation among SFS seedlings to nursery and field performance is not well-understood and may explain much of the inconsistency among reports about SFS (Castle, 1987). Seedlings divided into 2 groups according to their leaf morphology, varied

Table 2. Performance of 'Hamlin' trees on several rootstocks in a St. Cloud field trial planted in Sep. 1986.[z]

	Yield, boxes/tree		Juice quality, 1991-92 season[y]		
Rootstock	1991-92	3-yr cum.	Sol. solids conc.	Ratio	PS/box
Smooth Flat Seville	3.3 a[x]	5.4	10.0 ab	14.4 ns	5.1 b
C. obovoidea	3.2 a	6.1	10.5 a	14.5	5.4 a
Carrizo citrange	3.3 a	6.1	10.5 a	14.9	5.5 a
Swingle citrumelo	2.8 b	6.3	10.4 a	14.2	5.6 a
Cleopatra mandarin	2.7 b	4.7	9.8 b	14.4	5.1 b

[z]The trial involves more than 20 rootstocks. Trees on Bittersweet sour orange and standard sour orange are part of the trial but were too affected by CTV to provide acceptable data.
[y]Fruit harvested 14 Nov. 1991.
[x]Mean separation within columns (except 3-yr yield) by Duncan's multiple range test, 5% level. NS = nonsignificant.

Table 3. Cumulative yields (boxes/tree) of citrus trees on several rootstocks at the Division of Plant Industry Foundation Grove, Dundee.[z]

Rootstock	Scion				
	Nucellar Valencia[y]	Nucellar Navel[x]	Hamlin[w]	Redblush[v]	Marsh[u]
Smooth Flat Seville	17.6	27.5	19.2	46.9	41.7
Carrizo citrange	21.1	39.6	25.6	60.3	42.8
Cleopatra mandarin	20.2	20.2	28.7	49.7	43.6
Swingle citrumelo	18.1	—	24.1	42.2	37.3

[z]Annual data were averaged for variable numbers of budlines within a cultivar. See the following footnotes where no. of trees/rootstock = no. of budlines.
[y]38 trees/rootstock planted Feb. 1975; 9 crops.
[x]16 trees/rootstock planted June 1973; 10 crops.
[w]12 trees/rootstock planted Feb. 1975; 10 crops.
[v]14 trees/rootstock planted Feb. 1975; 8 crops.
[u]24 trees/rootstock planted Feb. 1975; 6 crops.

in their tolerance to *Phytophthora parasitica* Dastur and CTV (Grimm and Garnsey, 1968). Our isozyme results clearly showed that some zygotic seedlings were routinely missed during nursery roguing and, thus, were found among the trees in nearly all the commercial groves surveyed. Our field results also showed that the growth or yield of many trees propagated on a zygotic seedling did not seem to be affected, but some trees on off-type seedlings were stunted and/or affected by CTV. Smooth Flat Seville seedling populations should be carefully rogued. Additional study is needed to better identify seedling types and their characteristics.

Sour orange and SFS seem to compare favorably in many attributes. There are limited horticultural data from field experiments conducted in Florida (Hutchison and Bistline, 1981; Table 3) or elsewhere (Bevington and Cullis, 1990; Wutscher, 1977); however, when those data are combined with the observations from the Florida commercial plantings reported herein, SFS rates as similar, but not equal, to sour orange as a rootstock suitable for orange and grapefruit scions, tolerant of cold weather and adapted to a broad range of soil conditions including calcareous sites. We did, however, encounter one site (Grove F) where the soil pH was near 8 and most trees were healthy except a small group that had severe leaf micronutrient deficiency.

Given acceptable horticultural attributes, Florida citrus grower interest in SFS will then depend on CTV and blight tolerance and to a lesser extent on tolerance of other pests and diseases. The Grimm and Garnsey (1968) results and the preponderance of our field data indicate that trees on SFS are tolerant of blight and are substantially unaffected by the severe CTV strains currently present in Florida as compared to the decline and/or stunting induced in trees on sour orange; however, SFS is not as tolerant to CTV as, e.g., Carrizo citrange. Trees on SFS have declined in Australia from severe CTV strains not present in Florida and also as the result of infection of SFS seedlings in the nursery prior to budding. It may be that Florida trees on SFS are benefiting from natural cross-protection. Florida growers interested in SFS should use mild CTV strain-infected budlines until more is learned about SFS and CTV.

Bittersweet sour orange. This rootstock has been used commercially in Florida for many years, primarily in DeSoto and Hardee counties, and has been included in rootstock experiments (Table 3; Gardner and Horanic, 1966; Gardner et al., 1967). Bittersweet and standard sour orange are similar in essentially all rootstock characteristics (Castle, 1987). Bittersweet is susceptible to CTV. Mild strains were detected throughout the area we sampled without any apparent effect on tree growth or yield. The mild strains may be providing some measure of cross-protection, but when severe strains were detected, trees on BSO were declining or stunted.

Gou Tou and Zhu Luan. Both of these rootstocks were introduced from China. Their parentage is unknown but their isozyme genotypes have some similarity to those of sour orange and SFS. They are new to Florida where field trials have only recently been established. Seed are available and seem to yield seedling populations with little variation. Both rootstocks appear to have acceptable nursery characteristics; but, there are mixed reports about bud live and growth on Gou Tou. Field trees on Gou Tou have been more vigorous than those on sour orange. Gou Tou and Zhu Luan were of interest in China because of their CTV tolerance (Chao et al., 1979) which has been confirmed for Gou Tou by controlled studies in South Africa (Van Vuuren et al., 1991), Australia (Broadbent, pers. comm.) and locally (Garnsey, 1992).

C. obovoidea (Kinkôji). This rootstock is citrus nematode- and CTV-tolerant (Castle, 1987) and is probably a pummelo hybrid (Hodgson, 1967). The only Florida data available are those in Table 2.

Conclusion

While too little information is available to satisfactorily describe the horticultural characteristics of SFS, Gou Tou, Zhu Luan, or *C. obovoidea* in Florida, they may be acceptable substitutes for sour orange based principally on their tolerance to CTV. Field evidence also showed that SFS has

Table 4. Nucellar isozyme genotypes of sour orange, Bittersweet sour, and putative hybrids.

Rootstock	Enzyme system[z]				
	PGI	PER	PGM	SkDH	GOT-1
Standard sour orange	WS	FS	FS	FF	SS
Bittersweet sour	WS	FS	FS	FF	SS
Smooth Flat Seville	MS	FS	FS	SS	FS
Gou Tou	MM	SS	FX	FS	SS
Zhu Luan	MS	FS	FS	FS	FS
C. obovoidea	MS	FS	FS	MM	FS

[z]See text for enzyme names.

good tolerance to blight and high pH soils. Small scale commercial trials with each rootstock are justified.

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THE PERFORMANCE OF 'VALENCIA' ORANGE TREES ON 21 ROOTSTOCKS IN THE FLORIDA FLATWOODS

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Abstract. **'Valencia' orange, *Citrus sinensis* (L.) Osbeck, was grown on 21 rootstocks for 15 years in an area near Fort Pierce, Florida. There were four 8-tree replications in randomized blocks, with 4.6 × 8.2 m spacing. Yield was determined at 11 harvests, fruit quality at four harvests, and tree size (canopy volume) and surviving healthy trees were recorded. Trees on Sun Chu Sha (*C. reticulata* Blanco), Yuma [*Poncirus trifoliata* (L.) Raf. hybrid], Argentina trifoliate orange (*P. trifoliata*), and Smooth Flat Seville (*C. aurantium* L. hybrid) had the highest percentages of surviving healthy trees. Cumulative yield (kg/tree and kg solids/tree) was highest on Sun Chu Sha, Volkamer lemon [*C. limon* (L.) Burm. f.], sour orange No. 2 (*C. aurantium*), and Yuma. The largest trees were on sour orange No. 2, Yuma, and Sun Chu Sha.**

'Valencia' orange, *Citrus sinensis* (L.) Osbeck, is the major citrus cultivar grown throughout the world. It is grown extensively in Florida in the deep, sandy soils of the central Ridge and the shallow soils of the flatwoods. The Florida flatwoods soils are shallow over hardpans or limestone and range from acid to alkaline, poorly drained and highly variable. Extensive preplant site preparation is necessary, including the formation of beds to give the trees rooting space, the dredging of drainage ditches, and installation of irrigation systems because the shallow root systems make the trees drought prone (Wutscher and Bistline, 1988). The rootstock-related diseases of citrus blight (Smith and Reitz, 1977), citrus tristeza virus, and *Phytophthora parasitica* Dastur foot rot accentuate the production problems in the Florida flatwoods soils. Therefore, rootstock selection is a prime concern for ensuring the profitability of newly established citrus plantings in the flatwoods areas of southern Florida (Hutchison and Bistline, 1981; Wutscher and Bistline, 1988). This report presents information on the performance of a wide range of rootstocks grown in the flatwoods of southern Florida.

Materials and Methods

The planting site was near Ft. Pierce, Fla., where the soil was a shallow, poorly drained, fine loamy, depres-

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